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OPERATIONAL RADIATION PROTECTION AT THE KIEV'S RESEARCH REACTOR WWR-M

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Abstract
The research reactor WWR-M is in operation more than 50 years; at the same time the reactor technical condition allows its further safe operation in the case of upgrading of some systems and elements. The basic objective of the reactor modernization implies future utilization complying with the nuclear and radiation safety requirements. The radiation protection system is the subject of such modernization. An overview of the technical and organizational measures aimed on the radiation protection of staff and population at the reactor routine operation is presented.

Keywords
research reactor, radiation protection, staff exposure, radioactive release, radiation monitoring

1.Introduction

The WWR-M reactor is a heterogeneous water-moderated pool type research reactor operating with the thermal neutrons at a power level of 10 MW_{th}, giving a maximum neutron flux of 1.5×10^{14} $cm^{-2}s^{-1}$ at the core center. Main goal of the reactor use is the generation of neutron beams for the research purposes in different areas of physics and engineering. The reactor is equipped with 9 horizontal experimental channels, a thermal column, and 13 vertical isotope channels inside the beryllium reflector. The reactor is located at the site of the Institute for nuclear research (INR) in the Goloseev district of Kiev city. For more than 50 years of operation there was not any single incident with the exceeding of norms and conditions of the normal operation as well as there was no contamination detected above the established levels by radionuclides and aerosols for the free access premises.

Since 2001 INR has the permanent license for the reactor operation, which will be in force till the reactor final shut-down. The reactor final shut-down term is not defined yet and the reactor operation is carried out now in accordance with the separate permissions issued for several years. The basis of such extension for permission is the revised operational Safety Analysis Report, which must be approved by the Regulatory Body.

The National Academy of Sciences of Ukraine has approved in 2004 «The Strategic Plan for the use of research reactor WWR-M of the Institute for Nuclear Research». The Plan determines the strategic goal as the provision of the reactor operation till 2015, but now this timeframe is reconsidered towards the further extension.

Lifetime for the reactor vessel and primary circuit is not determined by the design documentation. Surveys performed since 1988 until now provide evidence that there are no negative changes beyond the design limits in the reactor vessel and primary circuit components. Upgrade of the reactor systems or replacement of the specific equipment was aimed on the safety improvement during the reactor operation. All reactor systems were upgraded completely or partially at the time of reactor many-years service. The basic objective of the reactor modernization implies its future use complying with the nuclear and radiation safety requirements. The radiation protection system (RPS) is a substantial component of such reactor's modernization. Upgraded RPS along with other safety important systems meets all regulatory requirements for the regular reactor operation and operative decision-making in the case of radiation incidents as well as the forecast of possible emergency situations [1]. This paper presents the RPS functions, composition and tasks, as well as the analysis of the op erational safety during last years at the WWR-M reactor.

2. RPS structure

Radiation safety provision is the most important element of the whole technological chain at the reactor operation. The staff, population and environment should be protected from the all kinds of radiation hazard [2]. Safety is provided in accordance with the requirements of acting normative documents, norms, rules and standards. The Norms of Radiation Safety of Ukraine [3] is the main state document that establishes the system of radiation and hygienical regulations to provide for acceptable exposure levels for both individuals and public. The norms establish the following categories of persons being exposed: *Category A (staff)* includes those individuals who directly handle permanently or temporarily sources of ionizing radiation; *Category B (staff)* includes individuals who are not directly dealing with sources of ionizing radiation but due to location of their working places within the premises and on sites of the engineering facilities where radiation and nuclear technologies are available could get additional exposure; *Category C* includes all the public. Exposure dose limits are 20, 2 and 1 mSv/year for the category A, B and C, respectively.

The radiation hazard from the WWR-M reactor regular operation is determined by following factors:

- *external gamma- and beta-irradiation* of different energies arising from the nuclear fuel and fission products, the induced activity of coolant, reactor constructions and units, corrosion products, the activated materials and samples;
- *neutrons of different energies* (from fast to thermal) from the reactor core. The neutron impact is possible inside the reactor hall nearby the experimental channels;
- *radioactive aerosols* arising from the fission-fragments and induced activity;
- *noble gases*: ^{41}Ar arising from the irradiation of ^{40}Ar in air by neutrons and the isotopes of xenon and krypton from the reactor core and primary circuit;
- *radioactive ^{131}I* from the fission-fragments;
- *radioactive contamination* of the working areas, equipment and overalls;
- possible penetration of the *activation products* from coolant and moderator into the air of working areas;
- *solid and liquid radioactive* waste.

The controlled area is established in the reactor building, i.e. the restricted area in which the special protective measures are or can be necessary with the goal of the exposure control or prevention of radioactive contamination spread at the reactor routine operation as well as the limitation of potential exposure [4]. All premises in the controlled are divided on three categories:

- non-attended – where the technological equipment and communications are located. The staff stay in these premises is forbidden. The access of staff to these premises is permitted for the survey, repair and equipment replacement only;
- semi-attended – where the radiation conditions allow the staff access during the limited time for the technological maintenance and repair works;
- attended premises – where the staff is staying during the whole shift.

The radiation conditions in the premises are depending on the reactor power; their typical values are presented in Table 1.

Table 1. Radiation conditions in dependence on the reactor power

Place	Power, MW_{th}		
	0	4.0	10.0
Volume activity of the noble radioactive gases, *Bq/m^3*			
Reactor hall (reactor cover plate)	-	1.3×10^6	1.6×10^6
Reactor hall (experimental channels)	-	1.1×10^6	1.4×10^6
Gamma-irradiation dose rate, *mSv/h*			
Reactor hall (reactor cover plate)	0.02	0.15	0.18
Reactor hall (experimental channels)	0.002	0.12	0.13
Pump-house	0.2	30.0÷90.0	38.0÷95.0

Natural background value at the reactor site lies in the range 0.0014 - 0.0017 mSv/h

Radiation protection program has established the main directions of activity for the reactor staff protection. The radiation control is executed for the monitoring of followings:

- conditions of protective barriers;

– activity of the primary circuit heat-carrier and other technological media:
– radionuclide content;
– dose rate in the premises;
– individual dose of external exposure.

Modernized RPS allows the complete fulfillment of the normative requirements at the reactor routine operation as well as the operative decision-making in the case of incidents and the technologic forecasting of possible emergencies.

Contamination by radionuclides and aerosols of the premises in the free access area above the established levels was not found during the long-term reactor operation. Unplanned contaminations of premises in the controlled area were occurring mainly due to the staff wrong actions during the maintenance, repair or experimental works. Generally, these are the local surface contaminations in the range 450-500 β-part /cm^2·min on the area no more than 1.5 m^2, which were removed by the standard decontamination methods within the working shift. Doses of external irradiation do not exceed the established control levels.

During the many years of reactor operation, the incident situations with the exceeding of regular operation limits were absent. The most of situations were connected with the automatic reactor shutdown. Such reactor shutdown (automatic drop of emergency rods) was caused by following reasons:

– short-term (< 1 s) disconnection of electric power – 22%;
– equipment malfunction – 58%;
– staff wrong actions – 14%;
– change of parameter value (above/below) from the established one – 6%.

The basic criterion of the RPS effectiveness is the absence of cases when the annual exposure limits are exceed. There are additional criteria such as the annual maximal and average doses of the staff exposure; the decrease of annual collective dose; the decrease of the aerosol activity in the attended premises; the number of cases with the exceeding of control levels.

3. Control levels

The control levels (CL) for the staff exposure (category A) are established for the operative control of the radiation conditions. These CLs are determined by the requirements of normative documents, the features of reactor technology, the available experience of operation as well as the state-of-the-art level of radiation safety [5]. Individual dose limits exist in order to protect individuals so that they do not receive an unacceptably high dose contribution while the collective dose is being optimized. These dose limits are naturally far below the values at which acute effects are manifested. CLs are a subject of revision once per three year, but they can be reconsidered in the case of changes affecting on radiation conditions. Present CLs established in 2010 are in force. The CL values are presented in Table 2. Moreover, at the corrective maintenance in the pump-house, at the reactor cover plate and in the sectors of horizontal experimental channels the dose limit is equal to 4.0 mSv per shift.

The control of individual external exposure dose during the radiation-dangerous works is carried out by means of individual dosimeters D-2P and ID-02. The dosimeters ID-11, DKP-50 and ID-02 are used in the case of emergencies. The result acquisition and analysis is carried out by PC code PIDK, and then these results are stored in the data-base. The statistical information on the staff external exposure in dependence on the duration and number of works is shown in Table 3.

As one can see, the annual average individual dose doesn't exceed 2.41 *mSv* (in 1999), which is significantly lower than the established limit. Dynamics of individual doses are depending on the character and duration of radiation-hazardous works and can be used as an explanation of the collective dose variation during considered period. Thus, the main radiation- hazardous works when the staff has the largest dose load are following:

– repair, assembling and dismantling of technological equipment, especially in the pump-house of primary circuit;
– works on the reactor cover plate, especially at the core reloading;
– replacement of cleaning resins;
– coolant sampling and analysis;
– collection, conditioning, transportation and storage of radioactive waste;
– all kinds of works with the spent nuclear fuel in the cooling pond.

In accordance with the results of individual dosimetry control during last decade, the cases of individual dose exceeding doesn't registered during the whole time of reactor operation.

Table 2. Control level values for the reactor staff

Place	Gamma-ray dose rate, *mSv/hour*	Neutron dose rate, *mSv/hour*	Concentration**		Contamination β-*part /cm^2·min*		Annual dose equivalent, *mSv*
			β-aerosols in air, *Ci/l×10^{-12}*	NRG in air, *Ci/l×10^{-8}*	body, overalls	functional surface	
Non-attended premises (pump-house)	0.2*	⊗	≤ 1.0	⊗	50	1000	14
Semi-attended premises (reactor cover plate)	0.2*	0.004	≤ 1.0	3.0	50	100	14
Other semi-attended premises	0.01	⊗	≤ 1.0	3.0	50	50	14
Attended premises	0.01	0.01	≤ 1.0	3.0	30	50	14
Radwaste storage	0.004	⊗	⊗	⊗	⊗	***	14
Spent fuel storage facility (BV-2)	0.01	⊗	≤ 1.0	3.0	50	50	14
Other attended premises	0.01	⊗	1.0	⊗	⊗	20	14
Free access zone	0.0007	⊗	⊗	0.5	⊗	***	⊗

⊗ - not established;
* - at the stopped reactor;
** - control of the aerosol activity concentration with the value below 1×10^{-12} Ci/l is impossible due to technical parameters of available radiometers. In the case of the value excess, the radionuclide identification and activity measurements are carried out by means of gamma-spectrometer.
*** - contamination is inadmissible

Table 3. Collective and individual doses

Year	Staff, cat. A	Duration of works, *hours*		Dose	
		total	av.	collective, *man×mSv*	averaged individual, *mSv/year*
1998	22	322.8	1.2	68.7	3.12
1999	32	635.1	2.9	140.2	4.38
2000	41	790.4	3.2	160.5	3.91
2001	49	995.6	3.8	168.9	3.45
2002	28	476.8	1.6	108.9	3.89
2003	31	616.2	2.6	125.0	4.03
2004	34	738.5	3.5	152.7	4.49
2005	29	613.2	2.8	132.7	4.58
2006	37	867.9	3.3	161.7	4.37
2007	35	220.8	1.2	89.6	2.56
2008	33	255.0	1.7	107.9	3.27
2009	47	488.3	2.8	104.4	2.22
2010	43	358.4	2.1	112.9	2.63
2011	48	420.9	2.4	93.1	1.94

4. Control of the radioactive effluents

The noble radioactive gases (NRG) and radioactive iodine isotopes are the main components of the reactor release into atmosphere. In general, the radioactive noble gases can not be detected in the environmental samples. They give rise to low doses to the population. ^{85}Kr is the only radionuclide with a half-life longer that a few days (10.7 years). It is detectable, in very low concentrations, in the atmosphere. ^{41}Ar is produced by the neutron activation of cooling air. Direct radiation from ^{41}Ar plume results in a significant fraction of the dose which the most exposed members of the public receive. In accordance with results of systematical measurements during 1979-2011, the activity of noble gases at the reactor operation was caused by following radionuclides: 41Ar – 95%; 85Kr – 0.8%; 88Kr – 2.5%; 135Xe – 1.7%.

The main source of external exposure among the iodine isotopes is ^{131}I (half-life is equal to

8.08 days), the releases of iodine isotopes took place continuously. The CLs for the aerosol-gases releases are determining the total radioactive release into environment through the reactor stack, their values are following: $1.0\cdot10^{12}$ *Bq/day* for the NRG mixture; $9.4\cdot10^{6}$ *Bq/day* for ^{131}I; $1.3\cdot10^{4}$ *kBq/day* for long-lived radionuclides (^{110m}Ag, ^{58}Co, ^{60}Co, ^{51}Cr, ^{134}Cs, ^{137}Cs, ^{59}Fe, ^{54}Mn, ^{95}Nb, ^{90}Sr, ^{95}Zr).

As a thumb rule, the concentrations of the released radionuclides into environment are often too low to be measurable. Therefore, the dose estimates for the population have to be based on modeling the atmospheric transport and environmental transfer of the released radioactivity [6].

The limits were established for the releases: total activity of noble gases should not exceed the value of 3.65×10^{14} *Bq/year* (activity concentration < 3.03×10^{6} *Bq/m^3*) and total activity of ^{131}I should not exceed the value of 25.9×10^{10} Bq/year (activity concentration $<4.07\times10^{-2}$ *Bq/m^3*). These release values lead to the exposure dose for the public individual equal to 8.8 and 51.5 *μSv/year*, respectively.

The collected results of the radioactive release are shown on Figure 1. As one can see, there is the dependence of the release values from the reactor total operation time; however, these values are significantly lower than established limits.

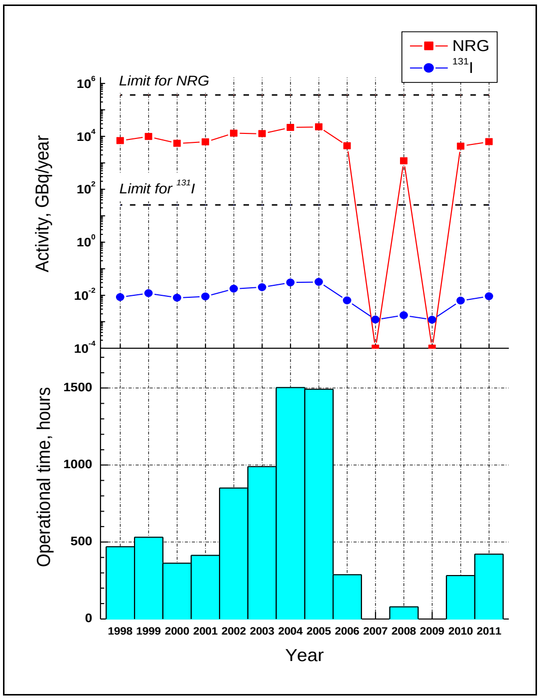

Figure 1. Aerosol-gases release during 1998-2011

5. External radiation monitoring

The discharge checks are supplemented by monitoring of the various compartments of the environment around the reactor, i.e. water, air, plants, soil and the components of the food chain. The monitoring program is regularly updated and tailored to the nature of the activities being carried out and the local characteristics of the environment. This system ensures that the provisions implemented by the facilities are effective.

Environmental monitoring traditionally comprises three functions:

– routine monitoring function. These routine measurements are taken in the site's environment in order to obtain a permanent reference datum, for use as a benchmark against which the measurements taken in the case of a radiological event can be compared;
– alert function, in the event of an abnormal rise in the level of radioactivity, via a network of permanent monitoring stations with real-time monitors of water and air quality in the reactor and their immediate environment;
– function for studying and understanding the working of the local environment, so that changes in radioactivity in the various compartments can be monitored over time and spatially.

The systematic radiation control of the rector's impact on environment is carried out continuously during the reactor operation. Main task of radiation monitoring is the overall control of gamma-, beta- and alpha-radioactivity as well as the content of basic radionuclides of reactor's origin (first of all, ^{3}H, ^{90}Sr and ^{134,137}Cs) in the environmental objects around the reactor's affected zone. The investigations are performed in 6 stationary points within the reactor site area (300 m) and 12 stationary points within the supervised area (3000 m), which were selected accounting the wind-rose. The subjects of interest are the following: the near-surface air; the atmospheric precipitates and settling dust; the water from the main collectors; the water from the open reservoirs (including the water flow of river Dnepr – above and below the rector's location); the water from melted snow; the birch sap; the soil and vegetation. The measurements of the short-lived and long-lived alpha- and beta-aerosol content in the near-surface air were performed too together with the measurements of gamma-radiation dose rates in the control points. Currently, there are following types of control: the air radioactive contamination; the water radioactive contamination; the soil radioactive contamination.

Function of the targets, the environmental monitoring program includes: a) routine monitoring program; b) emergency monitoring program.

The typical objectives (targets) of the environment routine monitoring are:

- verification of the radioactive emission monitoring program results and associated models - in order to check the protections supplied by the employed models;
- supply of required data for the assessment of current or potential doses to the critical group members, resulted from the decommissioning activity;
- detection of any unexpected modification of the radioactivity concentrations and the - evaluation of the long-term trends of the radioactivity levels in the environment as a result of the radionuclide releases to the environment;
- supply of information to the public.

Environmental Radioactivity Monitoring Program for emergency cases is designed in the way providing the fulfillment of the following specific objectives:

- supply, in due time, of the accurate data on the level and degree of dangers resulted from a nuclear emergency event and mainly on the environmental radiation and contamination levels;
- meeting the requirements for the personnel involved in decision making regarding the protection and repair actions;
- supply of required information for the protection of personnel involved in interventions;
- supply of information on the degree of the existing hazard for population.

As the whole, the results of radiation monitoring give evidence that the reliable increase of radionuclide content within the controlled parameters in comparison with the Kiev's typical ones was not founded during the whole time of investigations and this confirm the safety of reactor [7]. The reactor radiation impact on the environmental objects is very small and it is difficult to distinguish on the natural background and man-caused contaminations caused by the Chernobyl accident and global fallout.

6. Conclusions

The WWR-M reactor is an operational nuclear installation during more than 50 years and there are plans to continue its operation. Reactor is equipped by all necessary tools for the provision of radiation protection for the staff, population and environment. Long-term experience of the RPS operation has demonstrated its adequacy and efficiency. The reactor operation has negligible influence on environment and cannot be a reason of any negative ecological changes.

References

1. Shevel, V.N., Lobach, Yu.N. Makarovsky, V.N., Nesteruk, Yu.N. Solntsev, S.V. Improvement of the radiation protection system at the WWR-M reactor. Proc.2nd Int.Conf. “Current Problems in Nuclear Physics and Atomic Energy”. Kiev, June 2008. 650-652.
2. IAEA Safety Standards Series NS-R-4. Safety of research reactors: safety requirements. IAEA, Vienna (2005).
3. Norms of radiation safety of Ukraine. Additions. Radiation protection against the sources of potential irradiation, (NRSU-97/D-2000), Kiev, Ukraine (2000).
4. Lobach, Yu.N. and Shevel V.N. Radiation protection tasks on the Kiev's research reactor WWR-M. Nuclear technology and radiation protection. 24, 145-151 (2009).
5. Main Sanitary Regulation of the Radiation Protection of Ukraine (OSPU), Kiev, Ukraine (2005).
6. IAEA Safety Reports Series No.21. Optimization of Radiation Protection in the Control of Occupational Exposure. IAEA, Vienna (2002).
7. Tryshyn, V.V., Svarichevska, O.V., Pavlenko, I. O., Dzyatkovska, N.M., Sajenyuk, A.D. and Kuzmina, A.J. Radiation monitoring of environmental objects in zone of the influence of the RR WWR-M. Nuclear Physics and Atomic Energy. 11, 165-168 (2010).